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Evaluation of Obturator and Sealing Cuff Properties for the M865 Training Projectile With Comparison to Ballistic Testing

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Abstract

The nylon obturator and RTV sealing cuff for the M865 training round were evaluated to identify potential sources of ballistic variability associated with the material properties and material processing. While the properties of these materials are strongly dependent on processing conditions, temperature, and moisture content, the M865 performance variability is reduced by a well-engineered fracture mechanism that focuses the stresses in the obturator during sabot discard. A ballistic test was developed to validate the study. For the ballistic test, obturators were manufactured in "brittle," "tough," and "tough-wet" conditions. These three conditions produced significant differences in the mechanical properties (the maximum strength varied by a factor of 2, the elastic modulus varied by a factor of 25, and the elongation to failure varied by a factor of 10). However, the ballistic performance did not show any significant variability due to the obturator properties.

Acknowledgments

The authors would like to thank Mr. Ed Fennell, U.S. Army Armament Research Development and Engineering Center, and the M865 Process Variables Team for technical guidance and leadership throughout this project. The authors would also like to thank Dr. William Drysdale of the U.S. Army Research Laboratory (ARL) for his technical guidance on obturator performance. Also from ARL, Mr. Peter Dehmer, Dr. Travis A. Bogetti, Dr. Steven McKnight, and Dr. Nora Beck-Tan provided significant guidance on the properties of nylon materials; Dr. Peter Plostins led efforts to ensure that the ballistic tests were performed to meet the goals; and Mr. David Webb assisted in the design of the ballistic test as well as the data reduction from the test. Mr. Rollie Dohrn of Alliant Techsystems also contributed greatly to the success of this project by ensuring the proper manufacture and handling of the test projectiles. This work was funded through Mr. Robert Crawford, Rock Island Industrial Operations Command.

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1. Introduction

This project was initiated to evaluate the materials used in the nylon obturator band and rubber sealing cuff for the M865 training projectile, to assess the ballistic implications of the material properties, and to evaluate the performance during ballistic testing. A literature search and a series of analyses were completed to evaluate the potential effects of variability in the raw material properties, processing effects, and environmental effects on the ballistic performance. The range of properties was then used in dynamic analyses (Newill et al., to be published) to predict the potential effects on the in-bore behavior on the projectile. Based on this study, an experimental program was designed to test the limiting values ballistically. The results of the study (in section 4) showed that the obturator material properties had little effect on ballistic performance.

A schematic of an M865 projectile is shown in Figure 1, and a photograph of the original version is shown in Figure 2.

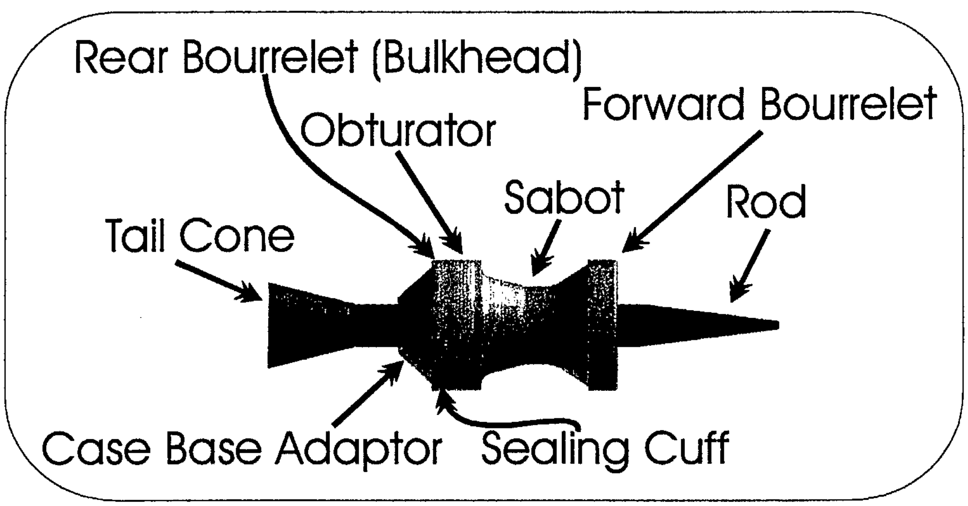

Figure 1. Schematic Diagram of an M865 Projectile.

The obturator band is located in the obturator seat on the rear bulkhead of the sabot. It is attached to the projectile with a knurled interface and helps hold the three sabot petals together. Notches are cut into the forward edge of the obturator and are aligned with the seams between sabot petals to initiate fracture of the obturator during discard. The M865 obturator is different from obturators on 120-mm tactical kinetic energy projectiles (M829, M829A1, and M829A2) in that it is broken during the discard process instead of at muzzle exit. The obturators on the M829, M829A1, and M829A2 are broken by the loss of the support from the tube as the bullet exits the muzzle due to the large internal pressure. The sealing cuff on the M865 is located aft of the obturator and is designed to adhere to the sabot during discard, tearing along the seams between the petals after the obturator breaks. The sealing cuff also provides some sealing of the projectile during launch.

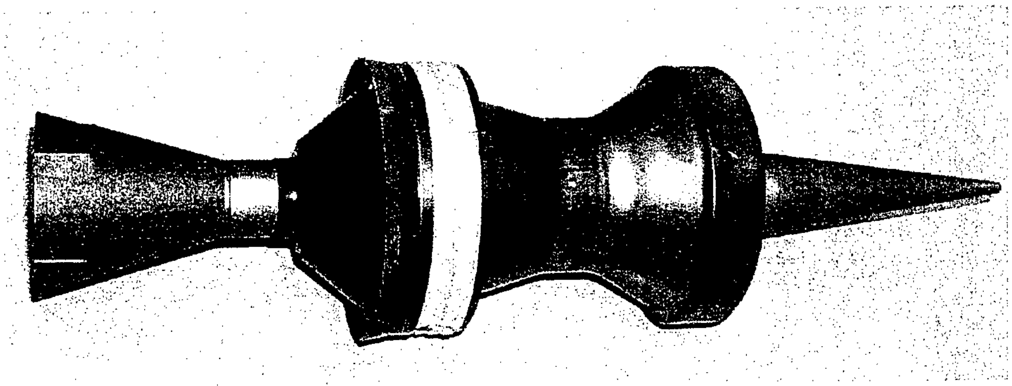

Figure 2. Photograph of an M865 Projectile.

Several problems involving the obturator and sealing cuff have occurred during production of the M865 projectile. The obturators have cracked during the final machining process, assembly, and handling of the projectile. Problems reported on the sealing cuff have involved occasional anomalies with discard. These problems have been attributed to poor interfacial adhesion between the sabot and sealing cuff.

2. Nylon Obturator Band

2.1 Raw Material Properties.

The nylon obturator band is made of injection-molded nylon 6,6. The specific nylon used for this program is DuPont Zytel 101. The raw materials are purchased to the specification for general-purpose nylon 6,6 in ASTM 4066-96a, "Standard Specification for Nylon Injection and Extrusion Materials (PA)" (ASTM 1996). The acceptance data from both of the contractors all met this specification and showed very low variability, indicating that raw material properties would have little influence on variability in the final molded obturator.

2.2 Processing.

The processing of the nylon obturators is much more significant in terms of variability in final properties. Two important aspects of processing are storage of the material prior to molding and material toughness. Material storage is important because it is critical that the nylon be protected from moisture prior to injection molding. Nylon is hydroscopic and will absorb moisture rapidly in ambient conditions. Any moisture in the nylon during the molding process will cause voids to be formed in the final part, making it brittle, or could damage the obturator's ability to seal.

Toughness in the material is also an important processing concern. It can be related to the amount of crystallinity and the structure of the crystals. In general, increasing the crystallinity makes the nylon more brittle. However, the structure of the crystals also is important. For equal amounts of crystallinity, small crystals produce a tougher microstructure than large crystals. The degree of toughness in the nylon can be controlled through the initial mold temperature and cooling cycle during the injection molding process. If the nylon part is cooled rapidly from the molding temperature, it will solidify into an amorphous structure before crystals form. If the material is cooled slowly, crystals will form in the nylon. The degree of crystallinity can then be adjusted by altering the cooling cycle.

The degree of crystallinity will affect the appearance and the mechanical properties of the nylon. An amorphous nylon can be translucent, or clear in color. In general, amorphous nylon will have a high degree of toughness, with a low elastic modulus and yield strength, and a high strain to failure. Increasing the crystallinity of nylon makes it more opaque (giving it a whiter color) and makes it more brittle. The brittleness increases the elastic modulus and yield strength and reduces the strain to failure of the material. Figure 3 shows how the stiffness of nylon varies vs. percent crystallinity for samples conditioned at three different moisture levels. The relationship between the yield strength of nylon 6,6 and percent crystallinity is shown in Figure 4. Both the elastic modulus and yield strength increases linearly with percent crystallinity.

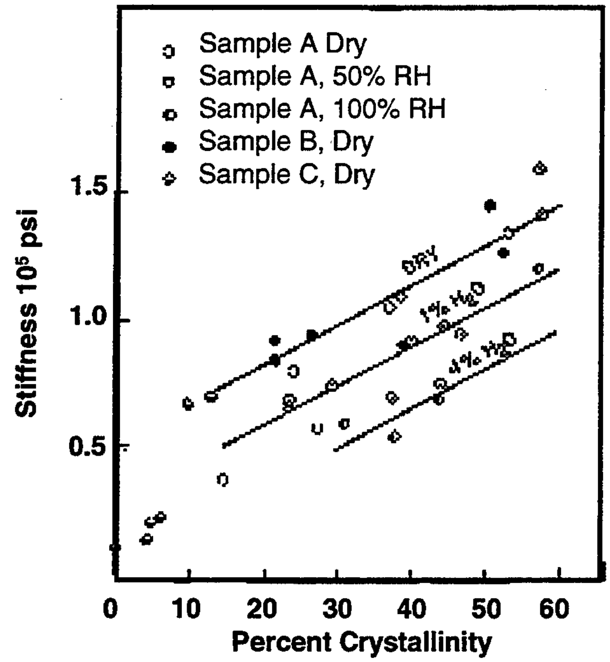

Figure 3. Stiffness vs. Crystallinity for Nylon-610 Films (Kohan 1973).

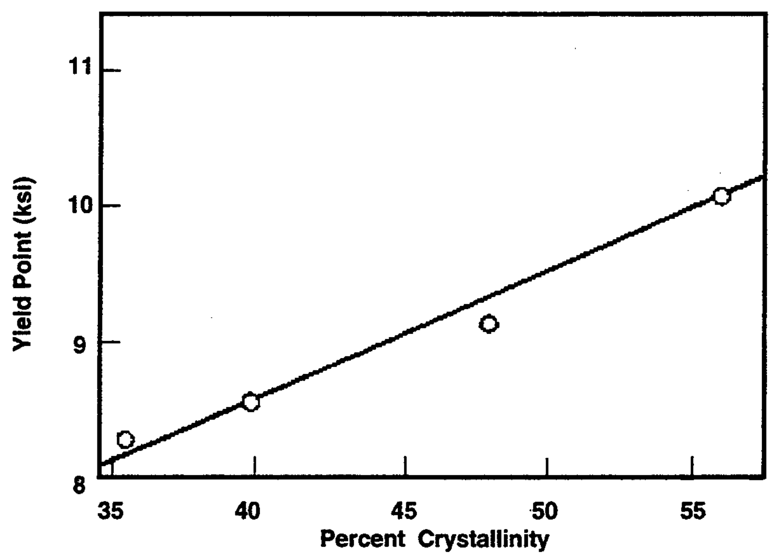

Figure 4. Yield Point of Nylon-66 vs. Percent Crystallinity (Kohan 1973).

2.3 Environmental Effects.

After nylon obturators are made, the moisture content and temperature can significantly influence their mechanical properties. As mentioned earlier, nylon is hydroscopic in nature and will absorb up to 8% moisture over time. Increasing the temperature of the specimens would greatly increase the rate of moisture absorption. In addition, increasing the RH levels would increase the amount of moisture that these specimens would gain since the saturation level of the material is proportional to the exposed RH (Tsai 1988). The absorbed moisture will cause the nylon to swell through hygrothermal expansion.

Absorbed moisture will also change the mechanical properties of the nylon. Figure 5 shows stress-vs.-strain curves for nylon 6,6 in the dry-as-molded (DAM) condition and a specimen conditioned to 50% RH. Note that the dry specimen is much more brittle. It is stiffer and has a higher yield strength than the specimen preconditioned to 50% RH (DuPont 1997).

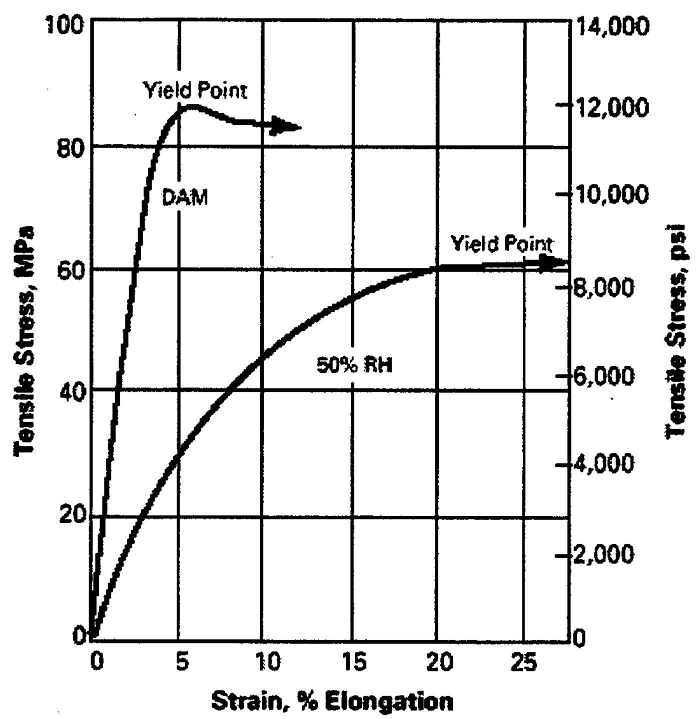

Figure 5. Tensile Stress-Strain Data for Nylon 6,6 at 23° C at 50% RH and Dry-as-Molded (DAM) Material Conditions (DuPont 1997).

Both increasing the temperature and increasing the moisture content reduce the stiffness and the yield point of the material. Figure 6 shows stress-vs.-strain curves for samples of nylon conditioned at 50% RH and four different temperature levels (DuPont 1997). At cold temperatures, the material displays brittle behavior, at higher temperatures, the material has tougher behavior. Figure 7 shows the effects of both moisture content and temperature on the flexural modulus of nylon 6,6 (DuPont 1997). Notice that over the normal operating temperature of the M865 (-25° F to 120° F), the modulus varies by a factor of 7, indicating that there can be substantial variation in obturator properties across the test temperature.

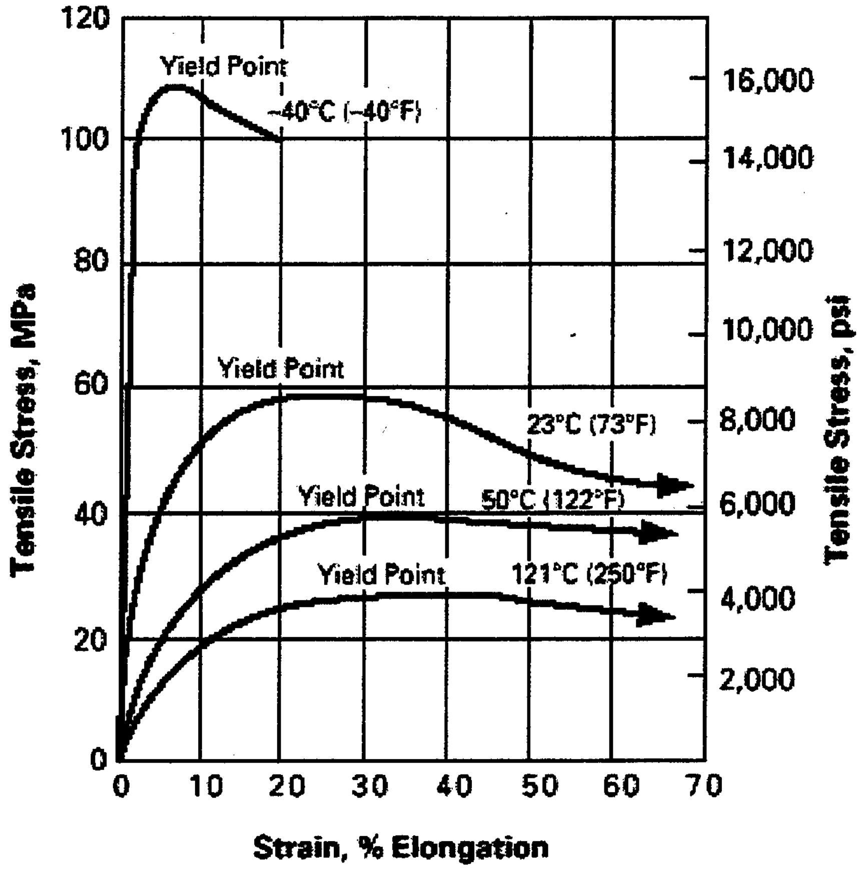

Figure 6. **Tensile Stress-Strain Data for Nylon 6,6 at 50% RH at Four Different Temperatures (DuPont 1997).**

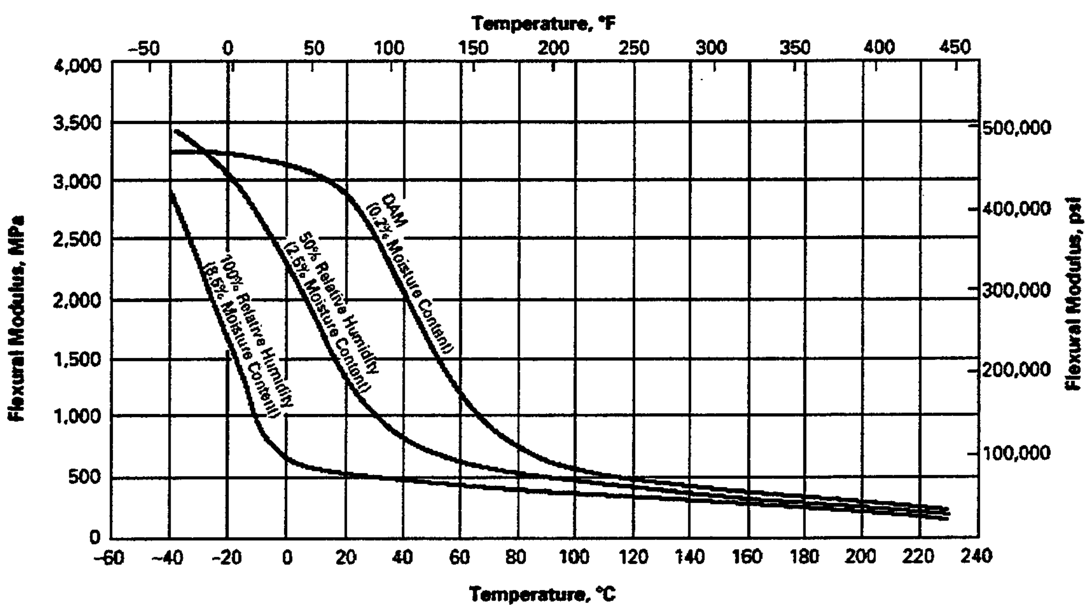

Figure 7. **Flexural Modulus of Nylon 6,6 vs. Temperature at Various Moisture Contents (DuPont 1997).**

Figure 8 and Figure 9 show the effects of moisture, temperature, and strain rate on the yield strength and elastic modulus of nylon 6,6. Moisture and temperature effects cause much greater changes in material properties than changes in the material strain rate.

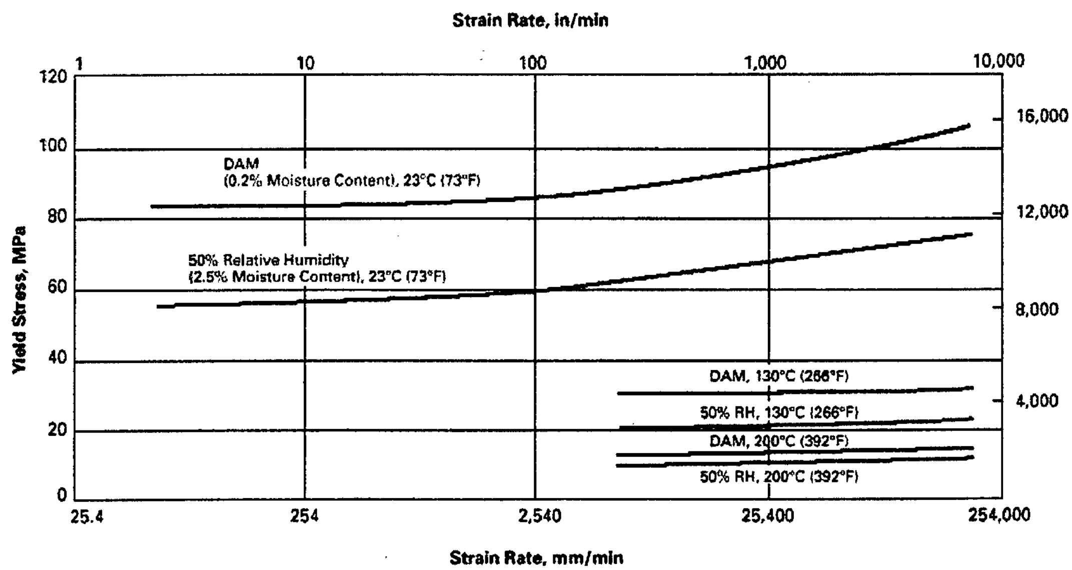

Figure 8. **Yield Stress Data for Nylon 6,6 Dry-as-Molded And 50% RH vs. Strain Rate and Temperature (DuPont 1997).**

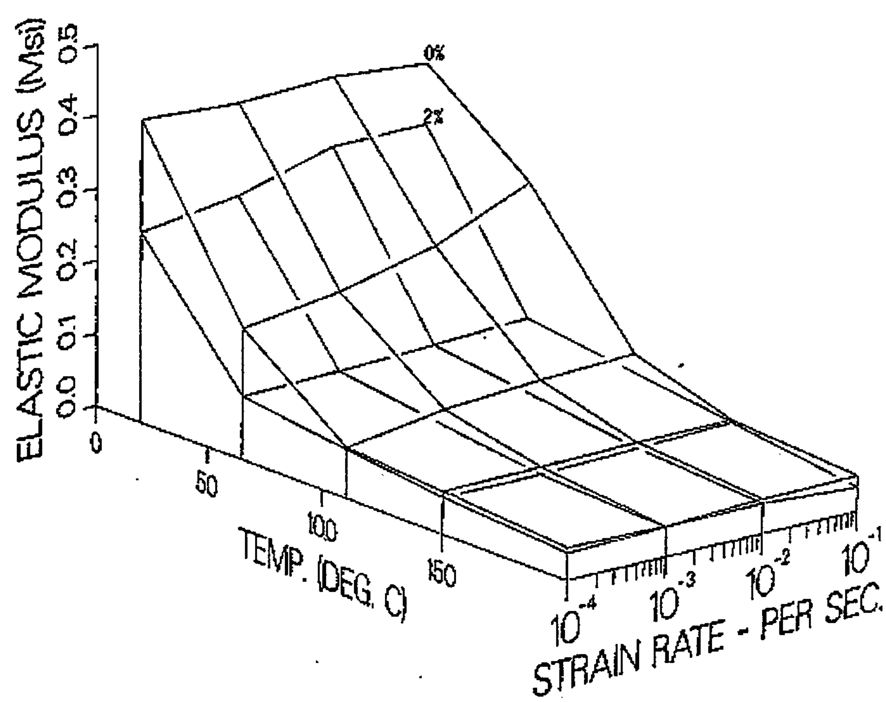

Figure 9. **Effect of Temperature and Strain Rate on the Elastic Modulus of Nylon 6,6 at Two Moisture Levels (Kawahara, Brandon, and Korellis 1988).**

2.4 Stress Concentration Due to Notch and Geometry.

While environmental effects can cause significant variation in the mechanical properties of the nylon obturator, the notches between sabot petals reduce variability in the behavior of the obturator during discard. In a separate study (Newill et al., to be published), the in-bore and discard behavior of the M865 projectile was numerically modeled. Figure 10 shows a finite element model showing the sabot discarding from the projectile. For simplicity of analysis, the notches in the obturator were not modeled. However, the analysis showed that during discard, the sabot geometry focused the stress in the obturator band such that the stress was three times higher at the sabot splits than in the surrounding material as shown in Figure 11. The stress is focused in a very small area because the obturator cannot slip on the knurled surface (due to the mechanical coupling) of the aluminum sabot. During discard, the elongation that occurs in the obturator will occur between the sabot petals. The distance between the sabot petals is very small, which in turn implies that the stress in the band is over a very short gauge length. This mechanism focuses all the energy from the petals separating into this very small area in the band, causing a large stress concentration.

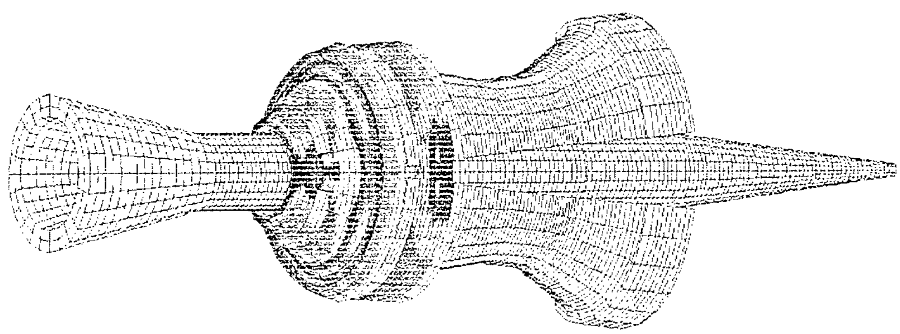

Figure 10. Finite Element Model of Sabot Discard.

The notch in the obturator further focuses the stress. The stress concentration due to the notch is defined by equation 1 (Hertzberg 1989):

$$k_t = \sqrt{\frac{a}{\rho}}, \tag{1}$$

where k_t is the stress concentration factor, a is the notch length, and ρ is the radius of the notch tip. For the notch lengths in the M865 (between 4 mm and 6 mm) with a notch radius of 0.25 mm, the stress concentration factor varies between 8 and 10.

The stress at the notch tip, due to a combination of the stresses from the sabot petals coming apart and the stress concentration at the notch, is then 24 to 30 times higher than the stress in the surrounding material. Since the stress at the notch tip is much higher than the failure strength of the nylon, variations in nylon material properties do not significantly affect failure of the band during discard.

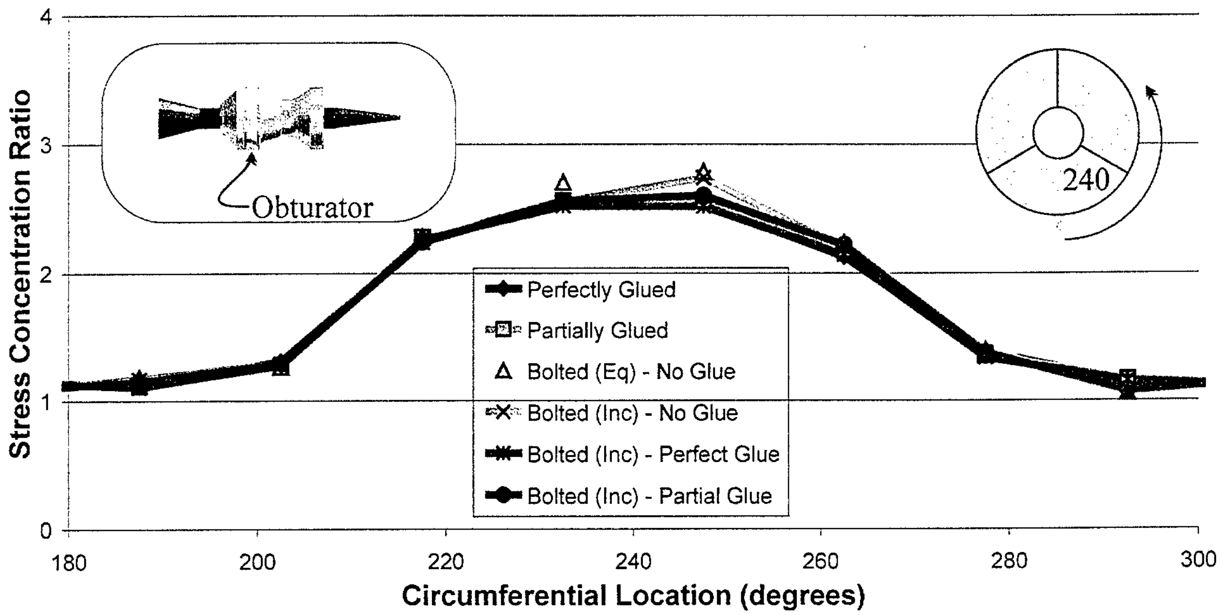

Figure 11. Circumferential Stress in the Obturator During Discard for an Unnotched Obturator.

3. Sealing Cuff

The investigation into the sealing cuff was more limited than the obturator portion. This was due to the development of the M865E3 version of the projectile, which is replacing the current sealing cuff with a nylon 6 snap ring adapter. In addition, material variations in the rubber have not been identified as a significant area of concern. A static break test was conducted on one projectile at Aberdeen Proving Ground (APG). In the test, the obturator dominated the lift-off process. Once the obturator fractured, the sealing cuff provided little resistance to the tearing lift-off loads. In this case, the RTV sealing cuff was well adhered to the sabot.

In the numerical discard analysis (Newill et al., to be published), the sealing cuff was modeled with several different interfacial conditions: perfectly bonded, partially bonded, no bond, perfectly bonded with a bolted sealing cuff, partially bonded with a bolted sealing cuff, and no bond with a bolted sealing cuff. The stress distributions at the leading edge of the sealing cuffs during discard for these cases are shown in Figure 12 and Figure 13. When the sealing cuff is perfectly bonded to the sabot, the stress is focused at the seam between the petals. This provides a short gauge section for failure between the petals. When the sealing cuff is only partially bonded or not bonded, the circumferential stress is no longer focused between petals and a much larger section of the sealing cuff can deform prior to failure. Since the sealing cuff is an elastomer, it can endure substantial deformation and absorb significant energy before it breaks, increasing the chance for irregular failure. Therefore, a poor bond between the sabot and the sealing cuff can lead to less repeatable discard behavior, inducing variability that may contribute to poor Target Impact Dispersion (TID). When the sealing cuff is bolted to the sabot, the failure of the sealing cuff/sabot bond is less dramatic. The bolts act as secondary stress concentration sites, initiating failure if the adhesive fails. The bolts therefore help reduce the potential variability due to poor bonding.

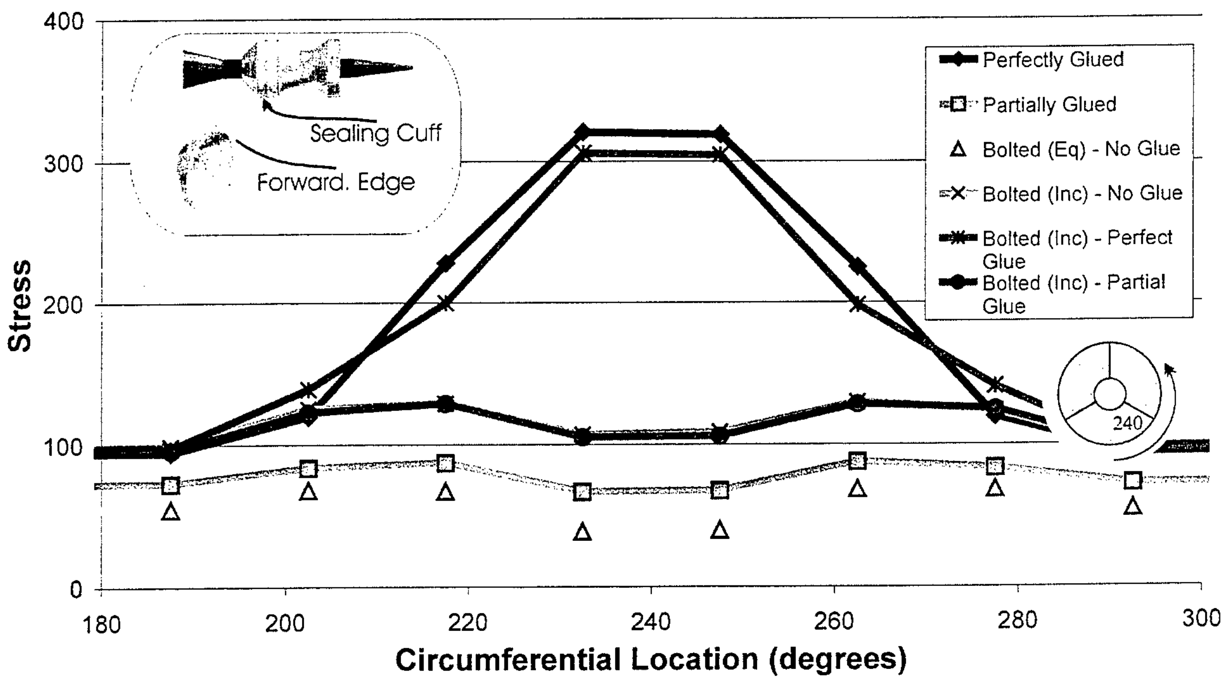

Figure 12. Stress Distribution at the Forward Edge of the Sealing Cuff During Sabot Discard.

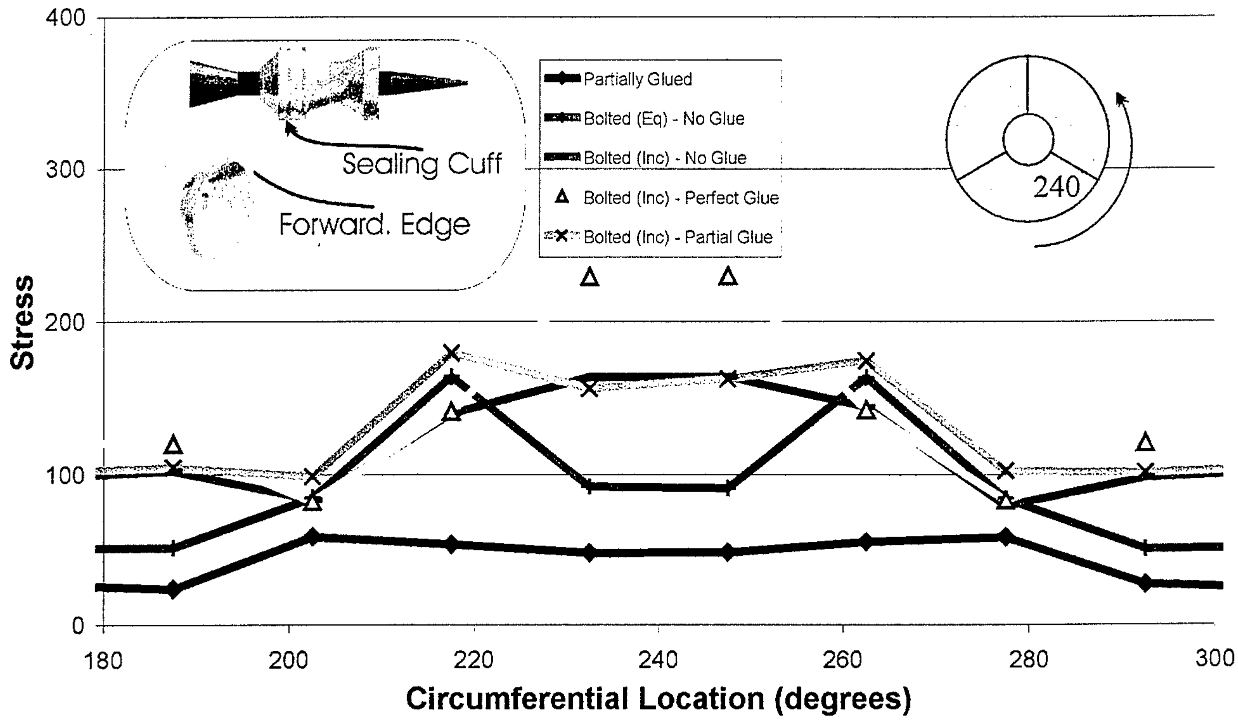

Figure 13. Stress Distribution at the Bolts in the Sealing Cuff During Sabot Discard.

4. Ballistic Testing

It was decided to pursue an experimental program to evaluate the effects of obturator properties on projectile performance. The two most important parameters that could affect obturator performance were identified as the toughness of the molded nylon band and the moisture content of the obturator. Three material conditions were then chosen for testing: a "brittle" condition with a low moisture content, a "tough" condition with a low moisture content, and a "tough" condition with a high moisture content (which further increases the toughness). The tough and brittle conditions were chosen based on reasonable molding conditions for the obturator and are described in section 4.1. The dry and wet environmental conditions were based on typical amounts of moisture in the obturator as described in section 4.2.

Based on an analysis prior to the test, it was determined that nine projectiles would need to be shot with each configuration to produce statistically meaningful results (Soencksen, Newill, and Webb, to be published). The ballistic test was also designed to evaluate the effects of bourrelet diameter on performance, which increased the number of configurations of test projectiles to include two bourrelet diameters. Therefore, 60 projectiles (9 test projectiles for each configuration and 6 spare projectiles) were manufactured for the test. The test matrix is given in Table 1.

Table 1. Test Matrix (Number of Projectiles for Each Configuration)

Diameter (mm)	Dry, Brittle Obturator	Dry, Tough Obturator	Wet, Tough Obturator
119.69	9	9	9
119.83	9	9	9

4.1 Material Mechanical Properties.

Test obturators were manufactured in the two conditions "brittle" and "tough." These conditions were achieved by controlling the processing parameters during the injection molding process. The details of the manufacture are contractor proprietary and therefore are not presented here. Several test specimens were manufactured with the same conditions, and their average mechanical properties are listed in Table 2. The tough specimens had approximately 4 times the elongation to failure as the brittle specimens.

Table 2. Mechanical Properties of the Molded Test Projectiles

Condition	Number of Test Specimens	Maximum Tensile Strength (psi)	Elastic Modulus (ksi)	Elongation to Failure (%)
Brittle	9	10487.6	191.2	11.79
Tough	6	9210.6	155.1	42.39

4.2 Environmental Conditions.

For the two environmental conditions ("dry" and "wet"), it was important to determine reasonable moisture levels for the projectiles (i.e., moisture contents that could be achieved in fielded ammunition). This would avoid biasing the test with "worst-case" environmental conditions such as an obturator completely saturated with moisture. Therefore, a study, described in section 4.2.1, was initiated to determine achievable moisture levels for nylon obturators. A second study, described in section 4.2.2, was then started to determine the best way to achieve these moisture levels.

4.2.1 Dry Out Testing.

The purpose of this test is to determine the moisture content of M865 projectiles that have been stored for long periods of time. Eight obturators were selected for testing. Four were manufactured in 1988 (lot number IOP88J058-003), and four were manufactured in 1997 (lot number MHM97K-002S295). One of the 1997 obturators broke in half when it was removed from the projectile, and each piece was used as a separate test specimen, so there were a total of nine test specimens. The 1988 projectiles had been stored in the open (not stored in ammunition cases) in bunkers at APG for approximately 10 years. The 1997 projectiles had been subjected to rough handling tests in December 1997, then sat for about 5 months in a propellant loading plant that had controlled temperature and humidity levels. The rough handling testing may have partially dried the obturators on these projectiles since it incorporates temperature cycling in a dry environment.

The projectiles were dried in an oven at 165° F for 32 days. The percent moisture loss vs. time is shown in Figure 14. The specimens from 1988 showed an average of 3.52% moisture loss by weight; the specimens from 1997 showed an average of 1.56% moisture loss by weight. Based on this study, it was determined that a reasonable moisture level for the "wet" obturators was 3.5% by weight moisture.

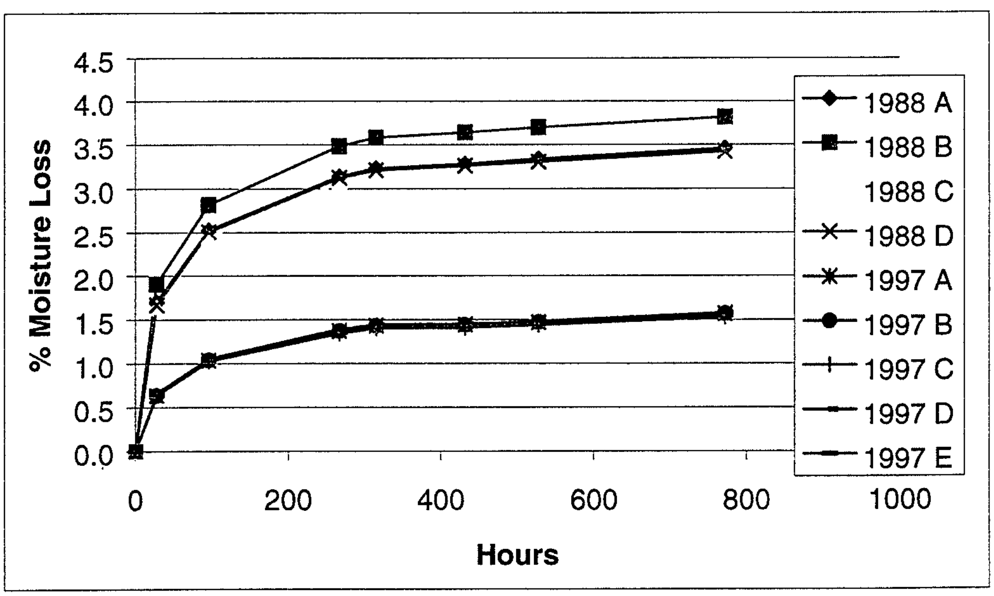

Figure 14. Obturator Moisture Loss vs. Time.

4.2.2 Moisture Absorption by the Obturators.

Moisture absorption tests were then initiated to determine the moisture saturation level and diffusion constants on the obturators. The obturators from the dry-out study were placed in two humidity chambers (50% RH and 90% RH) at 145° F. The percent weight gain vs. time is shown in Figure 15. The specimens conditioned at 90% RH had an average moisture saturation level of 5.67%. The specimens conditioned at 50% RH had an average saturation level of 1.93%.

From this study, it was interpolated that obturators with 3.5% moisture content would be in equilibrium in 75% RH air. It also showed that at 145° F, the obturators reached equilibrium moisture content within 20 days.

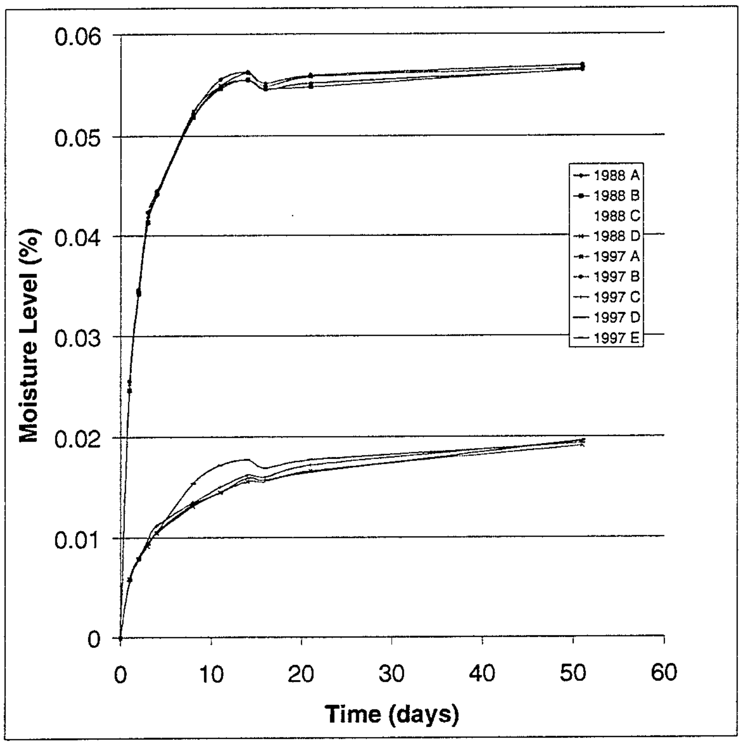

Figure 15. Percent Weight Gain vs. Time for Obturators Conditioned at 50% RH (Specimens 1988 C, 1988 D, 1997 C, 1997 D, and 1997 E) and 90% RH (Specimens 1988 A, 1988 B, 1997 A, and 1997 B).

4.2.3 Test Sample Preparation.

The test projectiles were manufactured in July of 1998. Three projectiles with removable obturators were made with the test projectiles in order to evaluate moisture content through the conditioning cycle. All of the projectiles were placed in ammunition storage cans and shipped to a separate location for environmental conditioning. At that time, all of the "dry" projectiles were sealed in Mylar vacuum bags. The "wet" projectiles were placed into a conditioning chamber at 145° F at 95% RH until the test obturators showed a weight gain of 3.5%. After environmental conditioning, mechanical tests were performed on companion samples of all of the materials. The results are listed in Table 3. It should be noted that that the maximum strength varies by a factor of 2, the elastic modulus varies by a factor of 25, and the elongation to failure varies by a factor 10 for the obturators.

Table 3. Average Obturator Mechanical Properties After Environmental Conditioning

Condition	Number of Test Specimens	Maximum Tensile Strength (psi)	Elastic Modulus (ksi)	Elongation to Failure (%)
Brittle	23	11057.9	576.0	7.75
Tough	12	9569.9	380.87	39.65
Tough-Wet	15	5907.7	23.4	71.62

The "wet" projectiles were then placed in Mylar vacuum bags, and all of the projectiles were shipped to an ammunition loading plant. At the load plant, the vacuum bags were removed and the projectiles were loaded, placed in ammunition storage cans, and shipped to the ARL Transonic Experimental Facility at APG, MD, for testing.

At the Transonic Experimental Facility, the projectiles were temperature-conditioned in environmental chambers prior to the test. The "dry" projectiles were stored at 120° F and 25% RH for a minimum of 24 hours prior to testing. The "wet projectiles" were conditioned at 120° F and 75% RH for a minimum of 72 hours and a maximum of 120 hours prior to testing. The dummy obturators were weighed prior to the ballistic test, and they had an average moisture content of 3.35%. The reason for conditioning the "wet" projectile with humidity for longer periods of times was twofold. First, since the testing was fired with a propellant temperature of 120° F, the moisture content of the obturators would have dropped due to drying. The conditions were chosen to bring the obturators back to the 3.5% moisture content. While the timeframe was too short to fully recondition the obturators, the critical area of the band is the base of the slot since this is where the failure will initiate. The condition just before firing will ensure that this region is at the appropriate moisture content.

4.3 Results.

The full results of the ballistic test will be described in a separate report (Soencksen, Newill, and Webb, to be published). However, this section reviews the results significant to the obturator performance. The projectiles were fired from an M1A1 tank, through the Transonic Experimental Facility. Spark shadowgraphs were used to establish the yawing motion parameters, which were extrapolated to determine first max yaw. Target impact was also recorded for each shot. The test was conducted on the E3 version of the M865 projectile as shown in Figure 16. The E3 version of the M865 differs from the original version in that it incorporates a nylon 6 snap ring adapter rather than the rubber sealing cuff used on the original version of the M865 as shown in Figure 17. The variability in the first max yaw results from the ballistic testing as measured through standard deviations was 0.44 for the dry brittle bands, 0.60 for the dry tough bands, and 0.47 for the "wet" tough bands (Soencksen, Newill, and Webb, to be published).

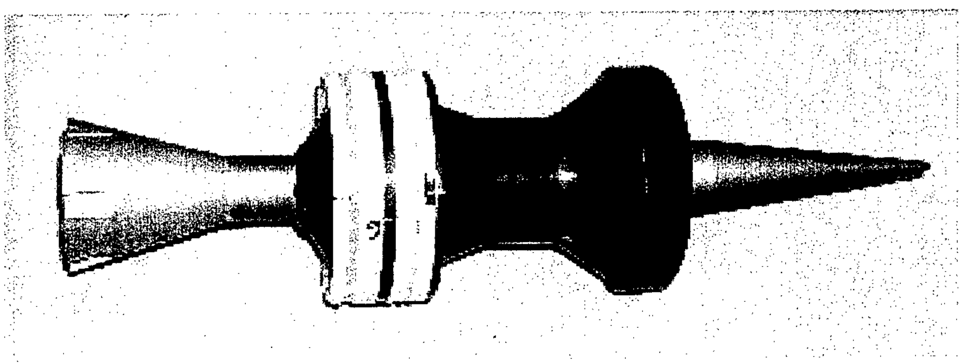

Figure 16. E3 Version of the M865 Projectile.

During the test, anomalies were noted in the fracture of the obturator. Several large pieces of obturators were recovered on the pad in front of the tank. The length of many of the pieces found was greater than that of the 120° sabot segment arc, which would have been expected for normal band breakage. Several of these pieces are shown in Figure 18 and Figure 19. The bands also showed signs of gas leakage underneath the obturators (Figure 20), and the aft potion of the bands were missing or badly damaged. The remaining sections of the aft portion of the band had a triangular cross section, which implies that they were worn irregularity due to gas leakage underneath pressing the band against the tube. Since gas leaked underneath the aft portion of the band in-bore, the loss of tube support at muzzle exit caused the aft portion of the band to blow off of the projectile. The leakage underneath the obturator and loss of the aft portion of the band disengages the knurled surface on the band seat. When the knurled surfaces are not engaged, the stresses in the band are not focused between the sabot petals during discard, leading to more erratic fracture. This is further supported with the recovery of the large section of obturator from the testing. The bands show that they did not fail at each of the slots as designed. Since the bands are not fracturing as designed, the effects of the obturator mechanical properties should be more evident. This is due to the reduction in stress concentration (predicted in section 2) due to the loss of the mechanical coupling from the knurling surface. It also allows the obturator to absorb energy over a larger area, leading to failure that is more erratic. However, the results show that there were no significant differences in obturator behavior, indicating that even with the reduced stress concentration, the differences in mechanical property still did not significantly affect discard. This also implies that if the band is performing properly (with the knurling surface intact), the material differences should have even less effect.

Figure 17. Comparison of the Original M865 Projectile (Left) to the E3 Version (Right).

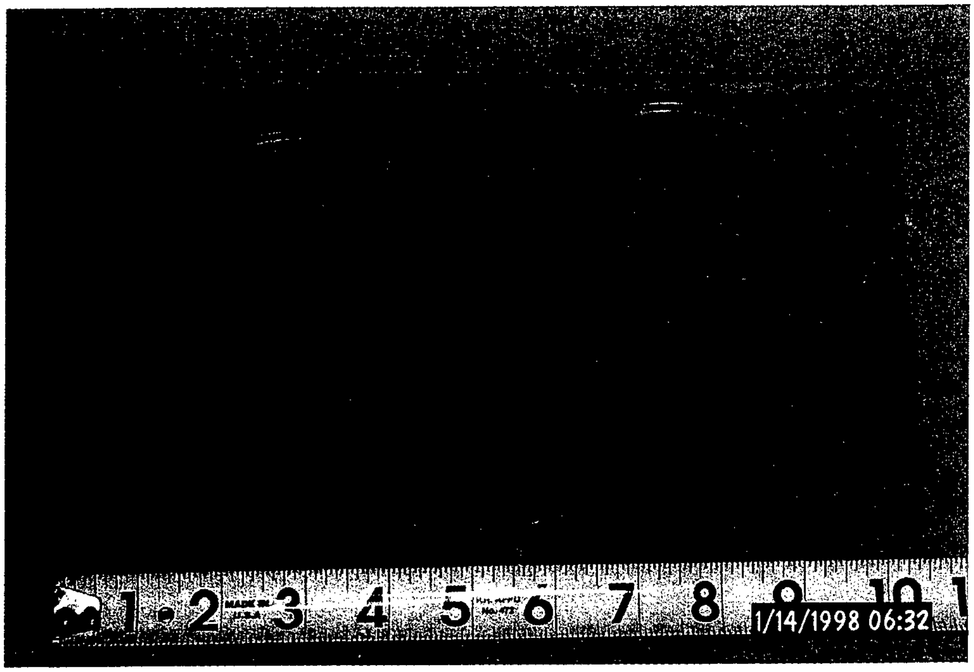

Figure 18. Obturator Pieces Found During the Ballistic Test.

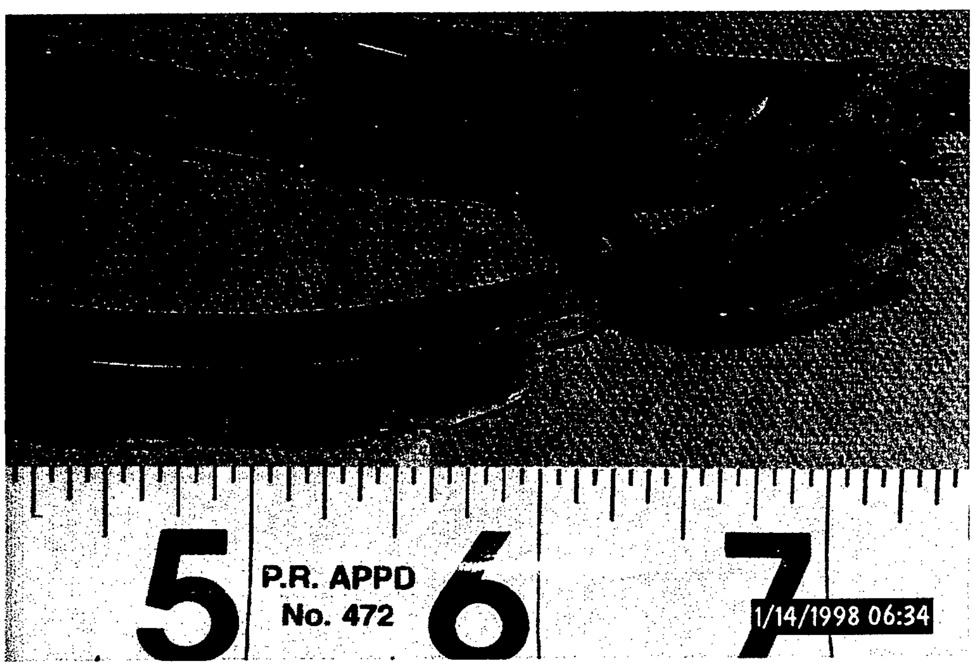

Figure 19. Close-up Photograph of Obturator Pieces Found During the Ballistic Test.

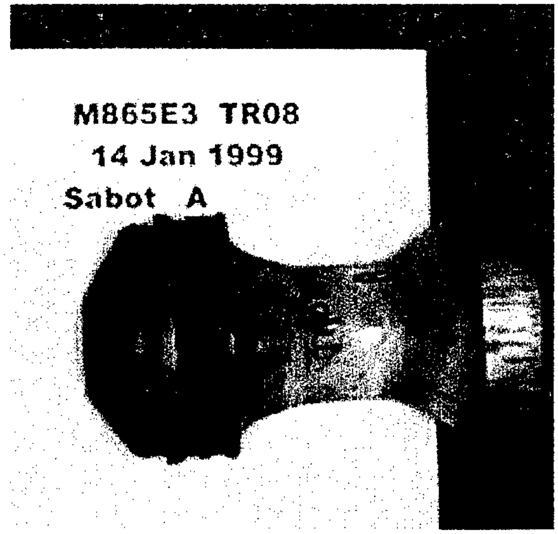

Figure 20. Sabot From a Separate Ballistic Test Showing Soot in the Obturator Seat Due to Gas Leakage Underneath Obturator.

5. Conclusions

Historical test data have shown that nylon functions well as an obturator material. It is used in many different types of ammunition and rarely causes problems. However, nylon can have a variety of properties, and these need to be understood. The toughness of the obturator can change significantly due to processing conditions, moisture absorption, and temperature. In the M865 obturator, variability due to processing is offset by the knurled geometry and notch, which focus the stress at the sabot seams. The ballistic tests in this study confirm that variability in the mechanical properties of nylon has little influence on sabot discard.

The obturator has several functions, which are contradictory with regard to the material requirements. During the manufacturing, handling, and storage of the projectiles, the obturator needs to be tough to avoid brittle cracking although nylon is most brittle in its dry-as-molded condition. As the obturator is exposed to ambient humidity levels, it will absorb moisture and increase its toughness. During discard, the obturator needs to fail in a consistent manner for each shot.

As described in section 2, the mechanical properties of nylon can vary by several orders of magnitude due to the processing conditions, moisture content, and temperature. This means that the obturator fracture can vary significantly due to the material properties. Therefore, an engineered breaking mechanism was designed into the obturator and obturator seat to overcome the material property variability. The knurled surface in the obturator seat on the sabot and the notch in the forward edge of the obturator both help to focus the stress and achieve repeatable failure. These failure mechanisms minimize the variability due the nylon mechanical properties during discard and, therefore, minimize the potential shot-to-shot variability.

The obturators used on the projectile in ballistic testing were made with a variety of material conditions. The results in Table 3 show that the maximum strength varied by a factor of 2, the elastic modulus varied by a factor of 25, and the elongation to failure varied by a factor 10 for the obturators in this study. It should be noted that these ranges of material properties do not represent extremes mechanical properties for nylon; rather, they are all conditions that could be reasonably seen in tank ammunition. However, the ballistic test showed no significant difference in first max yaw of the projectile's behavior, indicating that the variability in nylon behavior can be overcome with an engineered failure mechanism and therefore had little influence on projectile discard even with leakage problems underneath the obturator.

An issue that needs to be monitored is the manufacturing conditions of the obturators since these impact the material properties. Currently, there are no quality control tests or acceptance criteria for the molded projectiles, allowing the crystallinity and void content to vary significantly. While the ballistic testing showed that the variability can be overcome with mechanical fracture mechanism, controlling the source of the variability will ensure more consistent obturator performance.

The most significant issue with the sealing cuff appears to be adhesion to the sabot. Good adhesion focuses the circumferential stress in the sealing cuff at the seams and leads to consistent fracture. If the adhesion is poor or the adhesive interface fails, the bolts act as secondary fracture initiation sites. While this acts as an engineered failure mechanism, it is not as well done as the knurling/slot failure mechanism in the obturator. It appears that this portion is working well enough due to the good TID performance of the projectiles.

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The nylon obturator and RTV sealing cuff for the M865 training round were evaluated to identify potential sources of ballistic variability associated with the material properties and material processing. While the properties of these materials are strongly dependent on processing conditions, temperature, and moisture content, the M865 performance variability is reduced by a well-engineered fracture mechanism that focuses the stresses in the obturator during sabot discard. A ballistic test was developed to validate the study. For the ballistic test, obturators were manufactured in "brittle," "tough," and "tough-wet" conditions. These three conditions produced significant differences in the mechanical properties (the maximum strength varied by a factor of 2, the elastic modulus varied by a factor of 25, and the elongation to failure varied by a factor of 10). However, the ballistic performance did not show any significant variability due to the obturator properties.

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